Source Array Support for Continuous Monitoring of Fish Population and Behavior by Instantaneous Continental-Shelf-Scale Imaging Using Ocean-Waveguide Acoustics

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LONG-TERM GOALS

The goal of this effort was to provide use of the Flextensional Sea Test (FST) Array assembled under the Office of Naval Research (ONR) Multistatic ASW Capability Enhancement Program (MACE) as the source of underwater sounds to support active bi-static sonar capabilities for monitoring fish populations and behaviors during a September/October 2006 sea test off the coast of Maine. That sea test will be designated here as the Gulf of Maine (GoM) sea test.

OBJECTIVES

The objective for the SSC-SD team and equipment participation in the GoM sea test was to provide the equipment, its operation, and its maintenance for producing the underwater sound transmissions of the nature and at the times scheduled or requested by the GoM test director, Dr Makris, of the Massachusetts Institute of Technology (MIT).

A preparatory objective of the support efforts by SSC-SD personnel was to provide the expertise to advise Dr Makris, the MIT projector director, and his other support personnel of the capabilities, requirements, and limitations of the equipment required to plan for and provide the underwater acoustic transmissions needed to acquire the desired data. Such advisory interactions became critically important immediately before and during the initial phases of the sea test, because the smaller projectors (MOD-30 units) of the dual array had to be replaced shortly before the test with other units of very different performance characteristics and acceptable drive levels.

APPROACH

As the FST array hardware already existed and was suitable for the bi-static, active fish monitoring procedure planned for the GoM test, the approach for SSC-SD participation was primarily to arrange shipment of the array and support hardware to the Woods Hole Oceanographic Institute (WHOI), to

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install the system aboard R/V Endeavor as its operational-platform vessel, and to provide personnel for: installing the array-control equipment, operating and maintaining the installed transmission system, and removing the array-control equipment from the vessel after the sea test's end.

Another group of personnel were responsible for installation, operation, maintenance, and removal of the mechanical components of the array itself and its deployment and retrieval system. Figure 1 shows a picture of the array and its associated mechanical system as it appeared installed on the platform vessel. Figure 2 shows a close-up view of one of the seven hinging triadic sections that comprise the array. Two persons responsible for the mechanical system were provided by the Naval Facilities Engineering Service Center (NFESC), located in Port Hueneme, CA. They report separately from SSC-SD on aspects of this project relating to the mechanical system and its utilization for the GoM sea test.

Figure 1. The Flextensional Sea Test Array installed aboard the R/V Oceanus. Its large winch is immediately forward of the long deployment rack, which occupies almost all of the stern half of the vessel. The rack protrudes 3 feet beyond the stern end to allow the array vertical section to clear the stern. The red SSC-SD amplifier milvan is shown on the 01 deck directly above the forward end of the deployment rack and the winch, both located on the vessel main deck.

Figure 2. An XF4 and two MOD-30 projectors in a triad frame of the array. Five frames hold two MOD-30s and one XF-4. The two array-end frames hold only an XF4 each.

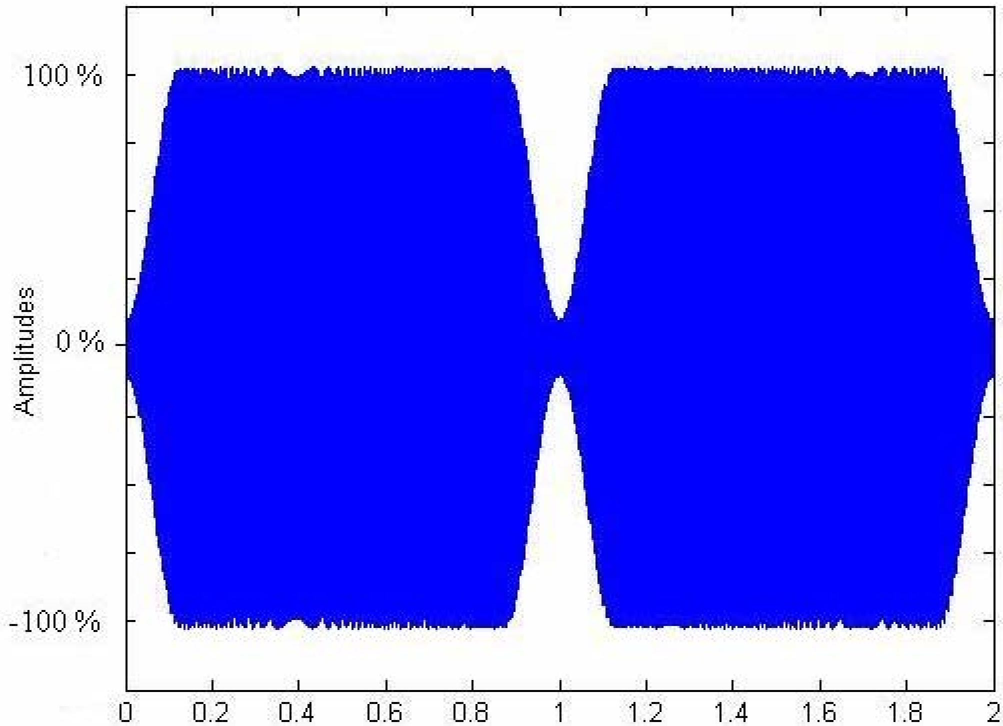

Figure 3. Wavetrain envelope used for both sub-arrays during the great majority of transmissions made throughout GoM sea test. Each of the two one-second pulses in the wavetrain is a LFM waveform.

Other than for the acoustic power level, the nature of each sound transmission was determined by waveforms stored in computer files. Such waveform files are uniquely named and then provided to our SSC-SD operator group prior to a sea test. Actual transmissions of the waveforms as underwater sounds are scheduled by assigned names and for assigned times and levels by computer files. These files are called control files, or "ping schedules), and must be constructed prior to or during the performance of the sea test. Each control file calls up a waveform file immediately before its waveform is to be transmitted, and the control file is constructed so as to call up many different waveform files at different consecutive times or to call up the same waveform file repeatedly. In either case, a sequence of waveform names embodied in a single control file can be constructed to provide transmissions of the waveforms over almost any length of time from seconds to days.

The envelope, or overall, shape of an example wavetrain is given in Figure 3. This wavetrain was transmitted by the XF-4 sub-array throughout almost all the sea test. Another wavetrain, transmitted by the MOD-30 sub-array had the same envelope shape as that in Figure 3, but the frequencies of the individual sinusoidal waves making up the envelope were higher than those of the XF-4 sub-array. Another difference is that the 100% amplitude of the MOD-30 envelope corresponded to a drive of 375 Vac(rms) instead of the 2000 Vac(rms) for the XF-4 drive level. This lower drive level for the MOD-30 sub-array is probably one reason why the received levels from this sub-array were generally lower than were those from the XF-4s. Each of the two wavetrains had two waveforms of one second duration each, as can be seen in Figure 3.

Each of the four waveforms for the two wavetrains was a Linearly Frequency Modulated (LFM) waveform. They were LFM because the individual sinusoidal waves of each waveform had frequencies that increased linearly with time from the start of the waveform. The individual waves cannot be distinguished in Figure 3. Each of the four LFM waveforms varied over a range of 50 Hz, with the XF-4 wavetrain having its two waveforms centered at 415 and 735 Hz and the MOD-30 waveforms being centered at 950 and 1125 Hz.

Figure 4 gives the characteristic source-level spectra of both sub-arrays of the FST array system used for the GoM sea test. These spectra are based on historical data, since accurate data could not be measured during the performance of the sea test.

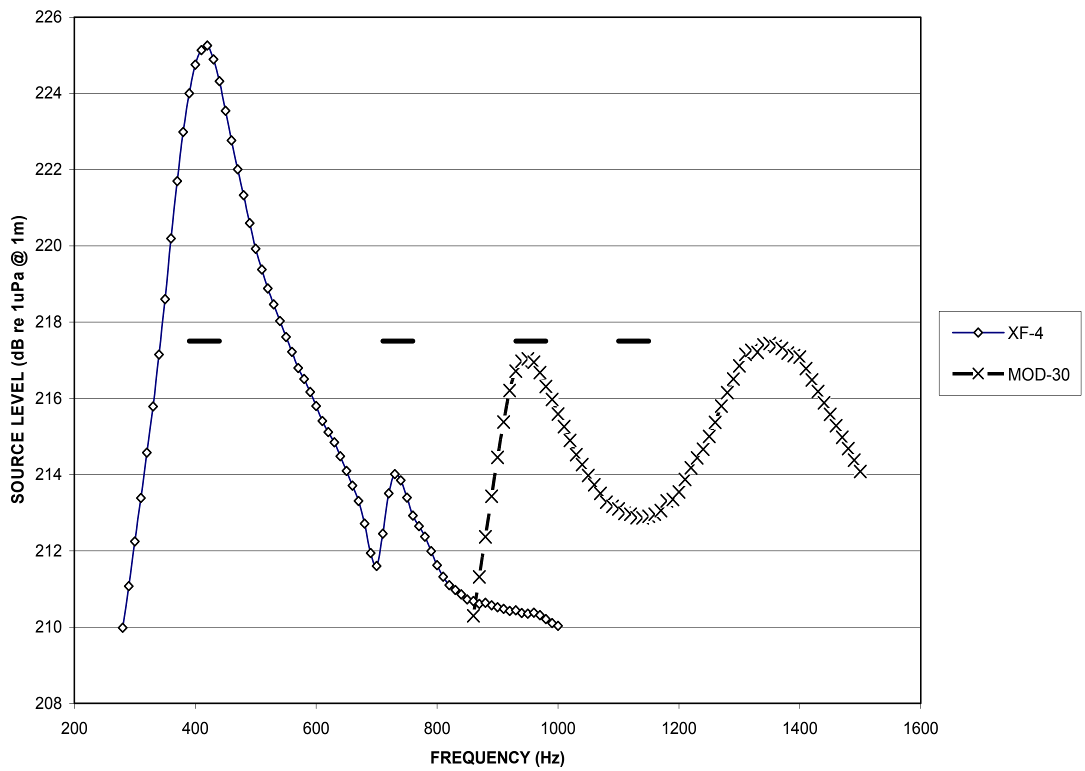

Figure 4. Source-level spectral plots of the two sub-arrays used in the GoM sea test. The four horizontal bars show the frequency locations of the four LFM bands used for almost all transmissions of the GoM sea test. It is readily apparent that the lowest frequency LFM had about 10 to 12 dB more output than either higher-frequency waveform of both wavetrains. Both MOD-30 LFMs were 7 dB or more below the level of the lower XF-4 band, due to the lower drive-voltage limit imposed on the tuned MOD-30 projectors.

The test director was aboard another vessel, the R/V Oceanus. Thus transmission schedules, schedule change requests, and other directives or communications were carried by radio links between the R/V Endeavor, the transmit platform, and the other vessel. This latter vessel was used to tow an acoustic receiver array and served as the primary acoustic receiver platform. The overall test system was an active, bi-static sonar system in that sounds were originated by the Endeavor, reflected off the fish and other underwater features, and then was received and recorded at the Oceanus.

WORK COMPLETED

Due to the exploratory nature of the data collection processes, the nature and extent of the transmissions to be made were not predetermined before the sea test, except for the estimated overall duration of the test performance. However, a set of wavetrains were made before the test, and, after some brief initial transmission/reception checks, the pair used for the rest of the testing was selected from among those of the set. At least about 70 - 80 hours of transmissions were accomplished in all. These were scattered over ten days of the three-week test duration and were made with no significant down times attributable to the array or its associated equipment. During the scheduled transmission times, an occasional ping was missed by operator error or was transmitted twice by computer error, but there were not enough such errors to concern to the test director. Most of the potential transmission time lost was due to the presence of marine mammals near the transmit system vessel. Time was also lost due to other causes such as: environmental effects such as rough seas, transits of the transmit system vessel, and turns of the receiver vessel and its towed array. However, near the planned end of the testing, the test director decided that enough data of sufficient quality had been gathered, and the testing was terminated one day earlier than had been planned. After the Endeavor returned to WHOI, he announced that the data acquired with the transmissions that were accomplished would satisfy his goals for the tests.

RESULTS

The participation of our source equipment and personnel in the sea test was, as stated above and as planned, in the support role of providing underwater sounds of a specific nature and timing to allow utilization by other groups involved in the testing. Transmissions were made mostly with a repetition rate of once every 100 seconds, although some others were made with 50 and 75 second periods. Using the 100 second rate and the estimated total transmission time of 70 - 80 hours, one can find that somewhere between 2000 and 3000 transmissions were made. These were made over the course of 10 days and at all hours of the day and night. From these considerations and the fact that the test director expressed satisfaction with the results gathered with the towed receive array, it can be concluded that the transmit system operation performed adequately in fulfilling its support role.

Due to equipment and operational constraints imposed by exigencies of the sea test, accurate measurements of the output levels of the two transmit arrays were not obtained. However, monitoring of the output levels by the marine mammal observers aboard the transmit platform and reports from the receiver platform indicated that the maximum output level for each array was about the expected levels shown in Figure 4. The XF-4 array appeared to hold this level rather consistently, but the MOD-30 array output appeared to be 5 to 10 dB lower and to vary by that much almost periodically. However, there were strong underwater currents that moved both the transmit array and the monitoring hydrophones. With its 10 units, the MOD-30 sub-array has a much narrower beamwidth in any vertical plane than does the XF-4 sub-array. A narrower beamwidth can produce greater change in received sound level than a broader one for the same angular change from vertical alignment by the transmit array, accounting for differences found by either the towed receive array or by the monitor hydrophone. The narrower beamwidth would have the same increased effect on the monitor hydrophone and attributable to their depth changes due to water current drag and to misalignment of the transmit array.

It seems appropriate to include here some remarks on differences in operation of the transmission system for this sea test compared to previous sea tests. The transmission system has two functionally separate sub-arrays whose projectors are interspersed throughout the mechanical fixturing used to deploy, suspend, and retrieve the arrays. One sub-array is composed of seven larger, low-frequency (400 Hz center) projectors designated by the model number XF-4, and the other sub-array is comprised by ten smaller, higher-frequency (nominally 1000 Hz center) projectors, called MOD-30s. Although it is typical usage of this system for transmissions to be alternated between the two arrays, on no previous sea test has the alternation been so persistent and frequent as for this sea test. Almost all sequences transmitted for this test alternated between the two sub-arrays every 50, 75, or 100 seconds for hours at a time, with each transmitted wavetrain lasting only two seconds. For all the days of transmission, except one or two, switching between the two arrays was done manually. In the many sea tests supported previously by the transmit system, usage of the two arrays was typically alternated after transmission durations of hours, or at least major fractions of hours, with each alternation following many transmissions by the same sub-array. Such operation was easily accomplished manually with toggle switches located with the other source-control electronics.

For the frequently repeating alternations of the GoM sea test, with each alternation following a single wavetrain transmission, an array-switching control box had been designed, constructed, and tested separately from the beamformer prior to the sea test. It allows the computer of the array beamformer to switch between the two sub-arrays under program control. However, when the control box was first checked for operation with the beamformer aboard the R/V Endeavor, it appeared not to function properly and was put aside for later assessment and possible repair, due to time constraints. The planned fall-back process of using manual array switching was used instead of the computer control of the switching. The control box and its associated computer files were later modified, tested, and then used to control transmissions. With the control box, the beamformer successfully controlled sub-array switching for a full twelve-hour day of transmissions with no failures of the programmed alternations. Its use was not available until near the end of the sea test, and most of the transmissions were accomplished by the manual switching, without any significant problems attributable to this mode of operation.

IMPACT/APPLICATIONS

In future sea tests, the array control box can be used to perform switching between the two sub-arrays under program control by the beamformer computer. Even if frequent alternation of the arrays is not needed, the programmed control will free system operators for other tasks and will make the switching more reliable than under manual control. Use of the control box requires no changes to the main software programs of the beamformer computer. Its operation requires only the addition of one (or optionally, three) simple files to the folder (directory) of waveform files, and the inclusion of a line statement to the sequence control (i.e., "ping schedule") whenever one of the switch-file changes is to be invoked. Use of this procedure does increase the size of the sequence control file significantly, but it also provides the capability of disabling the amplifiers between transmissions by the beamformer computer. This disabling capability is sometimes highly desirable, because the power amplifiers that drive the array projectors produce enough electronic noise when enabled to strongly interfere with the operation of other sensitive electronic systems that often share the support-vessel area where the MACE array control electronics suite is located.

RELATED PROJECTS

No other projects relate closely to the support participation of the MACE transmit system in the GoM sea test.